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ASIC VLSI chip using single electron transistors for traffic control system

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Abstract In integrated circuits devices with low power consumption high operating speed and high integration density equipment(s) are financially indispensable in modern Electronics Single Electron Device (SED) is one such device SEDs are capable of controlling the transport of only an electron or a few electrons A single electron is sufficient to store a bit of information in the SED Power consumption in the single electron transistor is significantly low compared to BJT transistor or CMOS transistor Power consumption can be drastically reduced by reducing the nodes The processing speed of SEDs will be nearly close to electronic speed Noise during processing becomes extremely low when the mode built with SEDs is in operation

Keywords Single-electron tunneling mode states operation speed

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1. Introduction

Delocalized electronic states and a quasi continuous spectrum of energies in the conduction and valence bands are the characteristics of the electronic structure of bulk semiconductors [1-3] But in low dimensional semiconductor structures carriers are confined in small regions of space in the range of a few tens of nanometers or below, and the energy spectrum is profoundly affected by the confinement [4-6] The energy spectrum is significantly affected

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when the width of the band gap is altered Moreover, the allowed energies are found to be discrete in zero-dimensional (0D) systems and form mini-bands in 1D and 2D systems [7-10] Confinement effects are much more serious in disordered and amorphous systems However, carrier confinement in low-dimensional semiconductor structures has several limitations which lead to a new principle of device operation as an alternative [11, 12] The new technique is a single electron based device which is a fascinating technology and provides a new physical effect of charge transport [13-15] This device has many benefits and great figure of merits [16-20] This device implies the possibility to control the movement and position of a single electron or a few electrons When people know the fundamental physical understanding of single electron devices and achieve at least for a laboratory setting practical manufacturing techniques, applications of such devices in circuits then become more expected items [21-25] Now it is the high time to initiate an extensive review of single electron applications in the areas of logic gates, memories metrology neural networks and many more Researchers have already focused their attention to understand the technological implications for digital and analog circuits and quest for meaningful applications [26-30]

The control system means a system by which any quantity of interest in a machine mechanism or other equipment is maintained or altered in accordance with a desired way [31-33] Consider, for example, the signal control in a traffic installed at a road crossing This traffic at such a place is a complex control system as situations are different at different time through out the day Here we have tried to tackle such a traffic control system with single electron devices to achieve a very high density of integration in the ASIC VLSI/ULSI chip thereby making the IC more compact and very less power consuming and suitable for use in today's and tomorrow's systems [34,35]

Single electron based logic gates have already been constructed with binary decision diagram with clock pulses of 1ns each [36,37] The technique of tunneling of an electron is utilized for those gates This technique may also be used for more complex logical circuit [38] like a **traffic control system.** For easily understanding the operation of the traffic system some gates having different number of inputs have been depicted [39] Single electron tunneling devices exploit effects that arise due to the quantized nature of charge These effects have been observed in systems of small metal structures [40], in semiconductors structures and in structures made from conducting polymers Because these effects are omnipresent in small structures, they are likely to have an impact on any future nano-scale electronic circuits These devices are able to use in low power circuits as only a few electron is needed for carrying information [41] The speed power product of single electronic device is predicted to lie close to the quantum limit set by the Heisenberg's Uncertainty Principle The processing speed of such device will be close to the electronic speed [42]

2. Realization of the circuit

Through this work single-electron devices like single electron based gates of 2, 3 or 4 input variables are made use of realizing a traffic control system. The control system is

realized through computer simulation where the whole system is produced through the pipelined processing.

Some single electron-based gates :

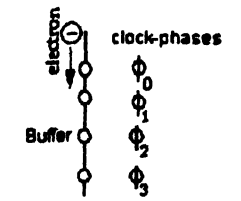

Figure 1. Buffer combination

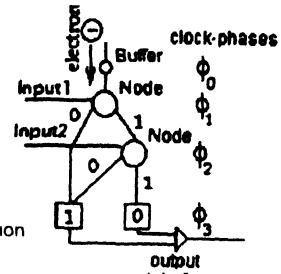

Figure 2. NAND

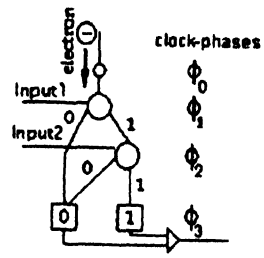

Figure 3 AND

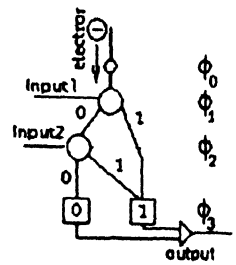

Figure 4 OR interface

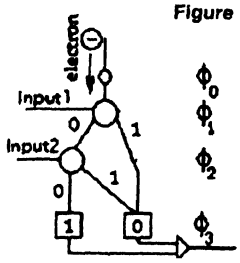

Figure 5. NOR

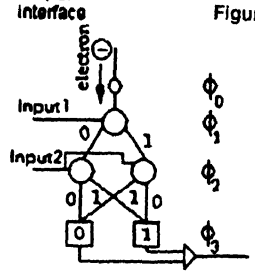

Figure 6. XOR

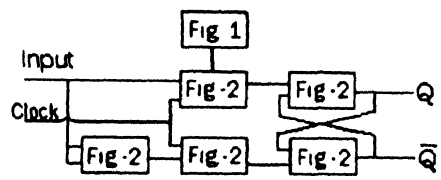

Figure 7. D-Flipflop

3. Description

To avoid traffic jam of two cross-sectional roads which are very busy, traffic control system has to be set at the intersecting point of these roads The system informs the drivers of cars what is to be done by glowing the different lights (*i.e.*, red, green and yellow).

In our system the traffic control systems operates with three modes (Normal, test and emergency modes) and four states (A_1B_1, A_2B_2, A_3B_3 and A_4B_4) For each state a particular time is allotted for each mode. In our consideration, we deal with two modes (Normal, Test) and the third one is considered as special case for which an indefinite time is scheduled for any state. Firstly, the emergency mode is put aside and the circuit is designed. After that a small modification is enforced upon the designed circuit to add the emergency mode.

Table 1. Mode and state duration

Mode → State ↓	Normal (sec)	Test (sec)	Emergency (sec)
A_1 B_1	05	15	Indefinite
A_2 B_2	10	15	Indefinite
A_3B_3	20	15	Indefinite
A_4B_4	30	15	indefinite

Design for normal mode

Four states (A_1B_1, A_2B_2, A_3B_3 and A_4B_4) are written in coded form *i e,* A_1B_1=00, A_2B_2=01 A_3B_3 =10 and A_4B_4=11 and two modes (Normal, Test) out of three are coded as Normal=1 Test=0 as well Our requirement for different excitation levels with respect to the circuit to be designed is shown in the tabular form in the Table 2

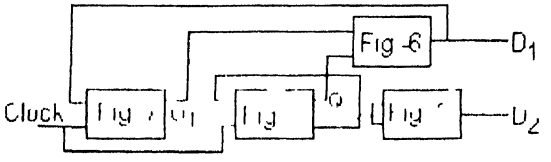

Figure 8 Exitation Circuit

Table 2. Records for Mode excitation

Mode	Clock	Q_1	Q_2	Excitation	
				D_1	D_2
1 or 0	↑	0	0	0	1
	↑	0	1	1	0
	↑	1	0	1	1
	↑	1	1	0	0

In normal mode, for each state a certain time is permitted and these time intervals are to be determined with the help of the present states and mode levels (0 or 1) To do this we have to construct a circuit by which the frequency of the clock of the D-flipflops are controlled by a variable time period clock *i e,* for different states with different modes the clock frequency will have to change according to our requirements Assuming that several intervals of time are permitted to different modes of the system In this situation we select four clocks of frequencies of 0 2Hz, 0 1 Hz, 0 05Hz and 0 0333 Hz The time intervals are logically encrypted as 5 sec=0 0, 10 ses=0 1, 20sec=1 0 and 30 sec =1 1 *i e* , the four clocks are selected as the inputs of 4X1 multiplexer with selected lines (S_0 and S_1) The select line inputs are generated with the help of the Table-3 S_0 and S_1 are defined as the functions of Input, Q_1 and Q_2

$$S_0 = \text{Input} + \bar{Q}_1$$

$$S_1 = (\text{Input} + Q_2)$$

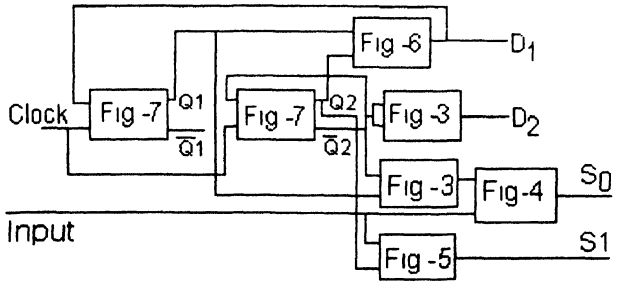

Figure 9. Sequence Selection circuit

Table 3. Sequence selection record control

Sl No	Input Q_1Q_2			S_0	S_1
1	0	0	0	0	1
2	0	0	1	0	0
3	0	1	0	1	1
4	0	1	1	0	0
5	1	0	0	1	0
6	1	0	1	1	0
7	1	1	0	1	0
8	1	1	1	1	0

The Input clocks of the D-flipflops are being controlled by the 4x1 multiplexer outputs which are controlled by the Input and present states of D-flipflops

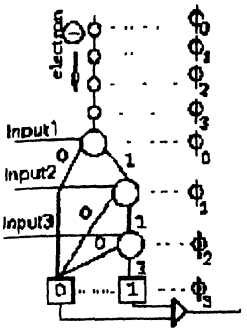

Figure 10. 3-input AND

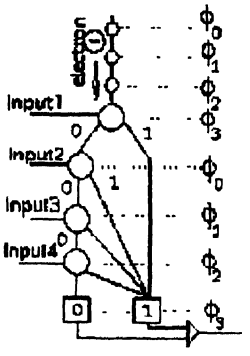

Figure 11. 4-input OR

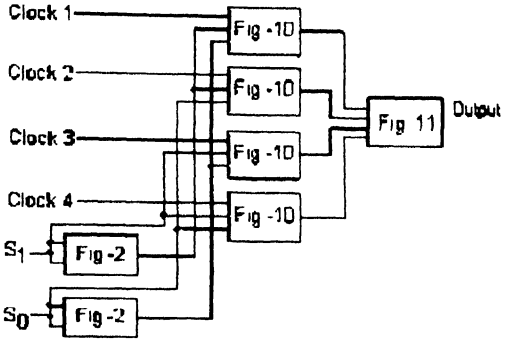

Figure 12. 4 x 1 Multiplexer

Now, we design the logic circuit that glows the different lights. The lights are controlled in full swing by the present states of Q_1 and Q_2 but, for the time being, the Input state, in Table 4, is considered as "Don't care". The logic equations of the circuit of the light are realized by the equations.

$$R_1 = \bar{Q}_1,\ G_1 = Q_1\bar{Q}_2,\ Y_1 = Q_1Q_2$$

$$R_2 = Q_1,\ G_2 = Q_1Q_2,\ Y_2 = Q_1Q_2$$

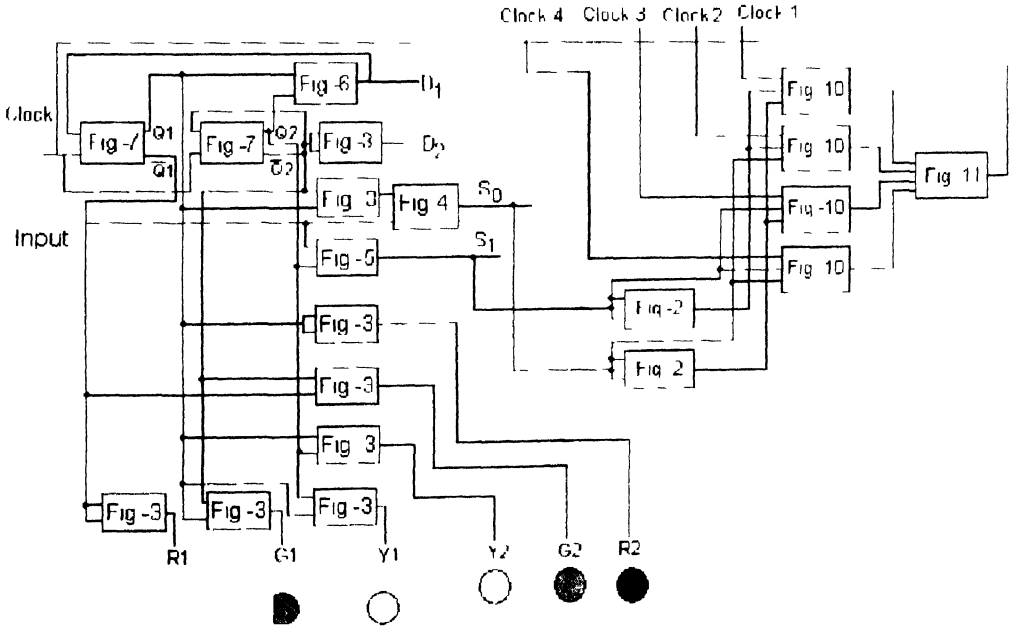

Figure 13. Traffic control system (Normal operation).

Table 4 Control Signaling sequence

Input	Q_1 Q_2	$R_1G_1Y_1$	$R_2G_2Y_2$
0 or 1	0 0	1 0 0	0 1 0
	0 1	1 0 0	0 0 1
	1 0	0 1 0	1 0 0
	1 1	0 0 1	1 0 0

If the Test mode had considered the time interval would be 15 sec, the input signals of the Input clock are to fix externally instead of the output of the 4x1 Multiplexer and the light glowing states would be the same as before(*i e*, as like as Table 4)

The emergency mode can be superimposed by deactivating the Normal mode and Test mode operations simultaneously and regulating the light glowing states by dint of input signal itself For obtaining this, emergency input line is connected with a signal E Then the light glowing system is modified as given below Circuit under emergency condition is depicted in Figure 14 where only red light is glowing

$$R_1 = E + \bar{Q}_1,\ G_1 = \bar{E}Q_1\bar{Q}_2,\ Y_1 = \bar{E}Q_1Q_2$$

$$R_2 = E + Q_1,\ G_2 = \bar{E}\bar{Q}_1\bar{Q}_2,\ Y_2 = \bar{E}\bar{Q}_1Q_2$$

Table 5 Control signaling sequence

Emergency input E	Q_1 Q_2	R_1 G_1 Y_1	R_2 G_2 Y_2
0	0 0	1 0 0	0 1 0
0	0 1	1 0 0	0 0 1
0	1 0	0 1 0	1 0 0
0	1 1	0 0 1	1 0 0
1	0 0	1 0 0	1 0 0
1	0 1	1 0 0	1 0 0
1	1 0	1 0 0	1 0 0
1	1 1	1 0 0	1 0 0

4. Time consumption

To transfer the messenger electron in the circuit, four-phased (Φ_0 through Φ_3) clock is applied to the nodes These clock-phase pulses are applied after 1 ns each To complete a phase cycle 4ns time is required [38] Any of the gates or buffer shown in Figure 1 through Figure 6 requires 4 ns to transfer an electron through it. For synchronization of

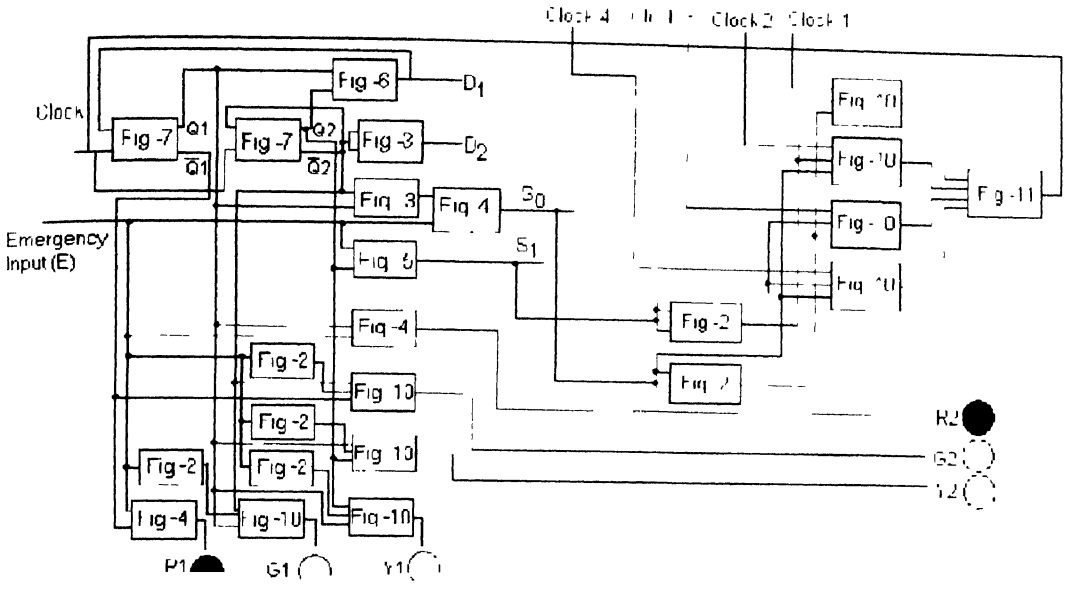

Figure 14. Traffic Control System (Emergency Mode)

signals, after pipelining, some buffers are added at proper positions in the circuit. In CMOS one NAND or NOR gate lapses some time (70ns) for processing the signal through it. In Transistor Logic Gates the minimum processing delay dime becomes 12ns [43] whereas to do the same job through a single electron gate the requirement time is 4ns[36,37].The processing time delay for conventional CMOS circuits and single electron devices are given in Table 5 and the related graph is give in Figure 15. It is seen that in accordance with the Table 5, the single electron device is at least 3 times faster than that of a conventional CMOS circuit. However the fastness depends upon the complexity of concerned circuit.

Table 6. Comparison of delay times

Serial No	Gates/circuits	Min Time spent for TL/CMOS (ns)	Time spent for SED (ns)	SED is faster (times)
1	Two input AND/OR/NOR/XOR/NAND/XNOR	12	4	3
2	Three input AND/OR/NOR/XOR/NAND	24	4	6
3	Four input gates	36	8	4 5
4	Excitation circuit	24	8	3
5	Control circuit	36	12	3
6	4x1 multiplexer	60	20	3

5.. Conclusion

Single-electron has the potency to operate with very low power supply and quantum properties impose a new principle of device operation thereby enhancing the signal processing capability. Heisenberg's Uncertainty principle, in our case, predicts the speed power product of an electron lie close to the quantum limit. This is why electron can

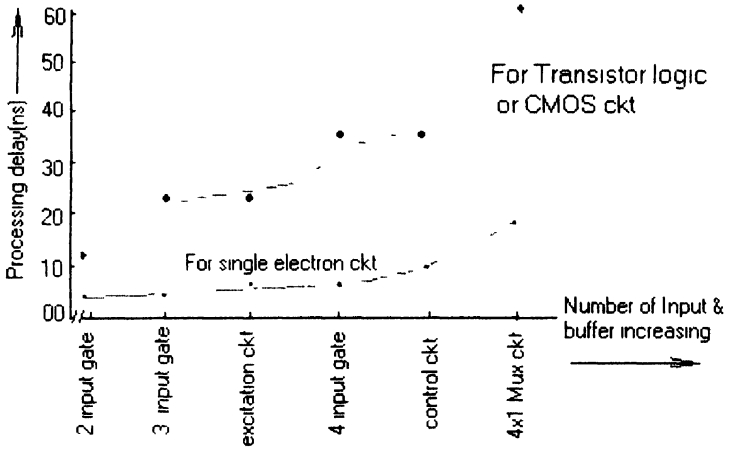

Figure 15. Processing delay variation for SET and cmos ckts

move through the single electron circuit with nearly close to the electronic speed. The efficiency of single electron circuits based Traffic Control System is found to be better than that of a conventional circuit. Single electron circuit operates at least 3 times faster than a conventional circuit. The Traffic Control System is really a innovative model based on single electron tunneling. Though it is complex circuit based on single electron transport, yet it provides ultra-dense device integration in the VLSI chip. Further it is cost effective and requires less operation time. The operation error caused by thermal agitation is excluded in the present model. The circuit built is really effective as it does not require any passive component like resistor, capacitor, inductor or diodes. Single electron circuit holds a small space so the integration density is higher than the present day VLSI/ULSI level.

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